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We received ROSAT data for four program objects : 3C31, 3C278, 3C449, and NGC1044. The first three sources were observed with the ROSAT HRI instrument. Our plan was to use the HRI to image the hot gas distribution in a few pairs of strongly disturbed interacting elliptical galaxies which are also strong radio sources having a bent-jet source morphology. The PSPC was used for NGC1044 in order to obtain a flux measurement to use in planning future HRI observations of that source. Though we never requested such HRI observations of NGC1044, others have used those archival PSPC data from our project for other research projects and analyses.

The goal of the program was to elucidate the detailed distribution of hot gas into which the jets flow. The X-ray data were consequently analyzed in conjunction with existing VLA radio maps, optical broad-band and H-alpha CCD images, and optical kinematic data to constrain models for the propagation of ballistic jets in interacting galaxies. We were ablte to test and validate the claimed causal connection between tidal interaction, the presence of gas, and the onset of activity in galaxies. We did not complete the full multi-wavelength multi-observatory analyses described here, but those are still on-going and will be published in the future.

Because of the relevance of this research to on-going work in the field of active galaxies, the grant was used to support travel to several scientific meetings where our x-ray analysis, numerical modeling, and related radio results were presented and discussed (see bibliography below). In addition, one collaborative visit to the University of Iowa was supported by the grant: the P.I. worked with astronomers Curt Struck and Phil Appleton to develop plans for performing numerical simulations that will include the hydrodynamics of the hot gas component. Struck and Appleton have developed a hydrodynamic code that can be used to meet the goals of this research program (specified above).

We published 3 refereed papers (see below) related to our numerical models and observations of colliding radio-jet galaxies. The models reported in our first papers made specific predictions about the distribution of the hot x-ray emitting gas in strongly disturbed colliding galaxies. Those predictions were subsequently verified in beautiful detail in our HRI observations of 3C278. An "ApJ Letters" paper presented those ROSAT results. We have confirmed the presence of a strongly distorted hot gas distribution in each of our primary sources, presumably resulting from the strong tidal disturbance of the colliding galaxy pair. The redistribution of hot gas is related to tidal deformation in the optical components of the galaxies (ie, the stellar mass distribution). We successfully related the complex x-ray morphologies in these systems to their radio jet morphologies. In each galaxy pair, the radio jet shows significant deflections at the kiloparsec-scale, again apparently resulting from the tidal interaction. The most likely interpretation is that the tides have directly influenced the hot gas distribution, whose subsequently induced pressure gradients are influencing (and thereby deflecting) the flow pattern of the radio jet plasma. The specific locations and gas densities at the points of deflection correlated well with the x-ray intensity pattern as well as to the optical distortions. Our results will be applicable to the general problem of wide-angle and narrow-angle radio tails often associated with the brightest members in rich clusters of galaxies.

Our deep ROSAT HRI imaging of the X-ray emitting gas associated with the colliding elliptical galaxy pair NGC 4782/4783 (3C278) revealed for the first time the complexity of the hot gas distribution in a pair of close interacting galaxies. The HRI image shows hot gas around each galaxy, a high-surface brightness X-ray bridge connecting the galaxy pair, tidal-like tails emerging from the two galaxies, and a sheet of gas at the interaction interface between the two galaxies. The hot gas distributions do not peak at the optical centers of the galaxies, but are displaced in the same sense as the tidal distensions seen in the optical luminosity distributions. All of these remarkable features show the complexity of structure that develops in the hot gas distribution when both hydrodynamical and tidal forces come into play during collisions between ellipticals with hot gas components.

Models by Borne & Colina of the bent two-sided radio jet 3C278 (associated with NGC 4782) indicated that there must be a strong interaction between the hot gas components of NGC 4782/4783 and that the deflection of the radio jets is likely caused by the ram pressure exerted on the jet plasma by the hot gas associated with the passing companion NGC 4783. These conclusions were qualitatively confirmed by the HRI image and substantiate the major role played by the hot interstellar medium, and its asymmetries, in the propagation and entrainment of radio jets in colliding radio host ellipticals.

Outside the scope of this grant, we still plan to accomplish other work in this research area (utilizing our ROSAT data in the analysis), including the following: We are incorporating our analysis of the ROSAT data into an analysis of a complementary set of ground-based optical and radio images. We have obtained optical spectroscopic measurements for most of the sources in our ROSAT sample, which will be used to elucidate the kinematics of these highly dynamical systems. The redistribution of hot x-ray gas is related to tidal deformation in the optical components of the galaxies (ie, the stellar mass distribution). We will relate the complex X-ray morphologies in these systems to their radio jet and optical morphologies.

Support from this grant was used to prepare and present two talks at conferences on the general astrophysics problem of "The Interaction-Activity Connection" among tidally disturbed active galaxies: Does the tidal interaction actually induce the activity seen in active galaxies? The results of our ROSAT observations are directly applicable to the study of the "The Interaction-Activity Connection".
Our conference papers on this subject were very well received, especially the paper presented at the 1995 Napoli Conference on Interacting Galaxies: this was an invited review talk. The paper presented at the Wurzburg International X-Ray Astronomy Symposium also stimulated numerous interactions with conference participants. To date, at least 3 new collaborative research endeavors have spawned off of the discussions with colleagues at those meetings.

Bibliography

Borne, K. D., & Colina, L., "Activity in Colliding Galaxies", in "The Nearest Active Galaxies", Madrid Conference, ed. J. Beckman (1992).

Borne, K. D., & Colina, L., "Radio Jets in Colliding Galaxies: Testing the Interaction-Activity Connection", in "The Evolution of Galaxies and Their Environment", Third Teton Summer School, ed. H. Thronson (1992).

Borne, K. D., & Colina, L., "Activity in Colliding Galaxies", Astrophysics & Space Science, 205, 217 (1993).

Borne, K. D., & Colina, L., "Ballistic Models for Radio Jets in Colliding Galaxies: 3C278 (NGC 4782/4783)", Ap.J., 416, 157 (1993).

Borne, K. D., "The Interaction-Activity Connection", invited review talk, to be published in the proceedings of the Napoli Conference on Interacting Galaxies (1995).

Colina, L., & Borne, K. D., "The Unusual X-Ray Collision Morphology of NGC 4782/4783 (3C278)," Ap. J. Letters, 454, 101 (1995).

Borne, K. D., & Colina, L., "The Unusual X-Ray Collision Morphology of NGC 4782/4783 (3C278)", in "Roentgenstrahlung from the Universe", eds. H.U. Zimmermann, J.E. Truemper, & H. Yorke, p. 427 (1996).

Borne, K. D., "Investigations of the Interaction-Activity Connection", Revista Mexicana de Astronomia y Astrofisica Serie de Conferencias, Vol. 6, "1st Guillermo Haro Conference on Astrophysics: Starburst Activity in Galaxies", Puebla, Mexico, p. 251 (1997).